Simulation studies on turbulent transport of multi-ion-species plasmas in helical systems

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Quantitative evaluations of anomalous transport fluxes of particles and heat in magnetically confined plasmas are critical issues for the design of fusion reactors. The gyrokinetic approaches are powerful to analyze the transport phenomena driven by the drift-wave plasma turbulences. Recently, we have extended the GKV code, which is a local flux-tube gyrokinetic code, to include the electromagnetic effects [1], and multi-ion-species plasmas with the precise collision operator [2, 3]. Using the code, we perform the gyrokinetic simulations for the turbulent transport driven by the ion temperature gradient (ITG) mode and the trapped electron mode (TEM) for multi-ion-species plasmas in helical and tokamak plasmas.

In high ion temperature LHD plasmas including multi-species ions (hydrogen, helium, and carbon) and electron with 'impurity hole' of carbon, the neoclassical and anomalous transport simulations are performed. The neoclassical simulations indicate the neoclassical particle fluxes of the electron and bulk ions are outward directed, while the flux of the impurity is extremely small which is sensitive to the radial electric field. On the other hand, the micro-instability analyses by the gyrokinetic simulations show that the ITG mode is dominant instability, and the quasi-linear particle fluxes of all species are inward directed. This results are consistent with the fact that the positive neoclassical particle fluxes and the negative turbulent fluxes should be balanced in a steady state with negligible particle sources for electron and bulk ions, except for the slight impurity carbon fluxes.

Hydrogen isotope effects in the ITG turbulent transport for LHD plasma through the equilibrium-scale electric field were investigated by the gyrokinetic simulations [4]. In contrast to the ITG mode, the TEM (collisionless TEM branch) is susceptible to the collisional stabilization. To clarify the impact of hydrogen-isotope species on such turbulent transport, TEM driven turbulent transport simulations in hydrogen and deuterium plasmas with real-mass kinetic electrons have been carried out. The linear analyses for the TEM stability show that the strong isotope dependence on the normalized growth rate of TEM appears through the stabilization effect due to the normalized electron-ion collision frequency. The nonlinear TEM turbulence simulations clarify the significant transport reduction of the electron and ion energy fluxes in the deuterium plasmas compared with the hydrogen plasma. In the deuterium case, the transport is reduced associated with the enhancement of the ratio of zonal-flow energy to total energy.

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